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DATA PAPER

Harmonised projections of future forest resources in Europe

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Abstract

• ***Key message*** **A dataset of forest resource projections in 23 European countries to 2040 has been prepared for forest-related policy analysis and decision-making. Due to applying harmonised definitions, while maintaining country-specific forestry practices, the projections should be usable from national to international levels. The dataset can be accessed at https://doi.org/10.5061/dryad.4t880qh. The associated metadata are available at https://metadata-afs.nancy.inra.fr/geonetwork/srv/eng/catalog.search#/metadata/8f93e0d6-b524-43bd-bdb8-621ad5ae6fa9.**

Keywords National Forest Inventory · Simulation · Modelling · Biomass · Carbon · Wood supply

1 Background

Balanced and optimal decision-making for forest-based bioeconomy and ecosystem services requires relevant, comprehensive, and reliable data. In addition, new forest-related policies at different levels and sectors of the European Union (EU) and reporting obligations related to international agreements and activities under the former Kyoto Protocol and the new Paris Agreement (Land Use, Land Use Change and Forestry; LULUCF), Convention on Biological Diversity (CBD), and United Nations Framework Convention on Climate Change (UNFCCC 2015) call for comparable data and information on the forest resources and their future development, of which the LULUCF Regulation (EU, No 2018/841) is the most recent, concrete example.

To better serve the increasing information demands, we present the metadata and future projections of the forest growing stock, above-ground carbon, and fellings in 23 European countries until 2040. The modelling was built upon the lessons learned from estimating and projecting sustainable future supply of forest biomass for different countries in Europe (Barreiro et al. 2016; Schelhaas et al. 2017). The results complement existing outlook studies, especially, the European Forest Sector Outlook Study II (EFSOS-II; UNECE/FAO 2011). While the EFSOS-II data provides information on the overall production and consumption of forest products between 2010 and 2030 under four policy scenarios, this study

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Contribution of the co-authors Jari Vauhkonen coordinated the compilation of the data and drafted the documents. The co-authors, listed in an alphabetical order according to the name of the country, analysed and compiled the data from their countries with the first author mentioned for each country as the coordinator of the country-specific work. Markus Lier managed practical aspects of the research project. Tuula Packalen coordinated the research project and supervised the work. All authors participated to commenting the documents and read and approved the final manuscript.

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focused on harmonised definitions, assumptions, and methodology to account for the administrative restrictions affecting forest use and, thus, wood supply for forest products.

2 Methods

2.1 Harmonising model-based biomass supply analysis

Based on earlier experiences, up or downscaling model projections between European, national, regional, and local levels can result in a large variation often attributed to uncertainties related to the data and models (e.g. Rettenmaier et al. 2010; Bentsen and Felby 2012; Neumann et al. 2016). However, the variation can also result from differences in how sustainability is taken into account and from the different definitions and assumptions of various ecological, technical, and socio-economic constraints (e.g. related to other forest ecosystem products and services) that limit the availability or accessibility of forests for wood supply (Alberdi et al. 2016; Fischer et al. 2016; Lind et al. 2016). National Forest Inventories (NFIs) and other ecosystem monitoring activities based on national sampling designs are reliable sources of national or regional forest-related information. The NFIs may also provide information on forest use restrictions, although with definitions varying between countries. If harmonised for assumptions and definitions (Henning et al. 2016; Korhonen et al. 2014), projecting these estimates towards the future can provide important information on the legal, ecological, or economic constraints of sustainable forest biomass supply.

On this background, this study is specifically intended to provide the first example of projections based on NFI data that are harmonised over Europe for definitions and assumptions regarding administrative restrictions that affect forest use (in particular, wood supply). For this purpose, we adopted the concept of "forest available for wood supply" (Alberdi et al. 2016; Fischer et al. 2016; Lind et al. 2016) and stratified the forest area of each country accordingly. First, we defined "Forests Available for Wood Supply" (FAWS) as in Lind et al. (2016): "forest where any legal, economic, or specific environmental restrictions do not have a significant impact on the supply of wood"; i.e. all forests except those with administrative restrictions. Second, we distinguished two categories where administrative restrictions constrained the forest use: "Forests Not Available for Wood Supply" (FNAWS) as "forest where legal, economic or specific environmental restrictions prevent any significant supply of wood*"* (Lind et al. 2016); and "Forests with Restrictions on Availability for Wood Supply" (FRAWS) as forests where forestry operations are restricted but (near-natural) management and therefore also wood supply is possible (for examples of such cases, see Korhonen 2016; Vauhkonen and Packalen 2017). When defining the categories, the harmonised definitions of Lind et al. (2016) were followed as closely as possible, but because of different forestry practices and availability of the information affecting the exact stratification, the rules applied for distinguishing FNAWS and FRAWS are presented country-specifically in the description file associated with the dataset.

We projected the forest growing stock, above-ground carbon, and fellings for the period of 2015–2040 accounting for the administrative restrictions described above. These attributes were selected as they are widely included in the measurement and estimation protocols of the European NFIs (Vidal et al. 2016) and their development is informative on the effects of administrative restrictions. The definitions of these attributes were harmonised according to experiences from earlier international processes and projects (Korhonen et al. 2014; Henning et al. 2016; Lind et al. 2016), with the guidelines given by Lind et al. (2016) recommended to be followed for these projections. To quantify effects of administrative restrictions, the projected forest attributes were considered to be points on Production Possibility Frontiers (PPFs) that indicate the combinations of future forest attributes that are possible, if the area available for wood supply is determined by the administrative restrictions. The number of PPF points that could be computed varied between the countries depending on the administrative information in the NFI data. By interpreting the administrative restrictions differently, we obtained altogether three sets of PPF points as follows:

PPF 1 (computed for all 23 countries) = all forest land assumed as FAWS regardless of true administrative restrictions; i.e. all forests were allowed to be harvested in the future simulations. This PPF point is strictly theoretical and following it would not respect legal restrictions or forestry practices prevailing in some countries. However, it provides a useful baseline for comparisons of the development of forest resources under the latter, more realistic future scenarios.

PPF 2 (computed for 20 countries) = FNAWS based on the administrative information in NFI data are excluded from FAWS; i.e., current administrative restrictions are used to restrict areas for harvests in the future simulations; and

PPF 3 (computed for 8 countries) = FNAWS are excluded as above and also FRAWS are accounted for based on administrative information in NFI data. The existence of information for this PPF in particular and therefore resulting forestry practice restrictions vary considerably between countries that is further explored in the following.

2.2 Modelling methodology

2.2.1 The European Forestry Dynamics Model (EFDM)

The European Forestry Dynamics Model (EFDM; Packalen et al. 2014) was developed to simulate the development of the forest and estimate the volume of harvested wood for any given forested area based on data from Europe's NFIs. In addition to even-aged forests (Packalen et al. 2014), the EFDM was parameterised for uneven-aged (Sallnäs et al. 2015) and, combining multiple Markov chain models, "any-aged" forest management (Vauhkonen and Packalen 2017). Due to its demonstrated flexibility, the main modelling effort of this experiment was carried out using the EFDM.

The simulations of the EFDM are obtained as Markov chains of possible future events and based on the well-known Markov property that the next state can be deduced from the present state according to transition probabilities. In the EFDM (Fig. 1), the transition probabilities are associated with a specified set of possible management activities. The initial state for the simulations is obtained by arranging the observations of the NFIs into a forest area distribution matrix according to pre-defined (ecological, technical, and socio-economic) factors that are assumed to affect forestry dynamics or reporting. During the simulations, the activity-conditional transition probabilities move proportions of forest land between the matrix cells and the projection of the forest area distribution in the future is obtained by running the simulations for a given number of time steps. As the development of area is simulated, separate transformation and state coefficients determined as mean values of relevant factors were derived from the NFI data and used to compute the values of growing stock volume, above-ground carbon, and fellings. For mathematical details, the reader is referred to Sirkiä (2012) or Packalen et al. (2014), whereas Schelhaas et al. (2017) review the EFDM principles in comparison with other models and Vauhkonen and Packalen (2017) provide insights on sensitivities and effects of parameterising the EFDM runs by data from various sources.

The EFDM was used for the projections of 20 countries following the method described by Vauhkonen and Packalen (2017) to adapt the EFDM corresponding to the current forest area distribution and business-as-usual forest management applied in each country (Fig. 1). The EFDM runs were parameterised and operated by national NFI teams' representatives, who also provided the required information on country-specific forestry dynamics. Each participant was instructed to use v. 2.0 of the EFDM, which can be downloaded from https://github.com/ec-jrc/efdm and run in the R statistical environment (R Core Team 2016) as open source code under the European Union Public License (EUPL). The participants were asked to initialise the EFDM using the most recent available NFI data as input. The projections were to start from the base year of the NFI data, which varied between countries (Table 1). Linear interpolation was applied between projected years unless the projection interval matched with the requested reporting years 2015, 2020, 2030, and 2040.

The composition of the matrices and management activities varied between countries according to factors affecting the forestry dynamics in each country. The participants were instructed to parameterise the EFDM to project business-as-usual forestry practices, referring to typical management applied in each country that can be defined in the confines of model requirements and possibilities of the data (e.g. what administrative forest use restriction categories were available in the NFI data). A general guideline was to use the expert information within the NFI team or country group (Table 1) to

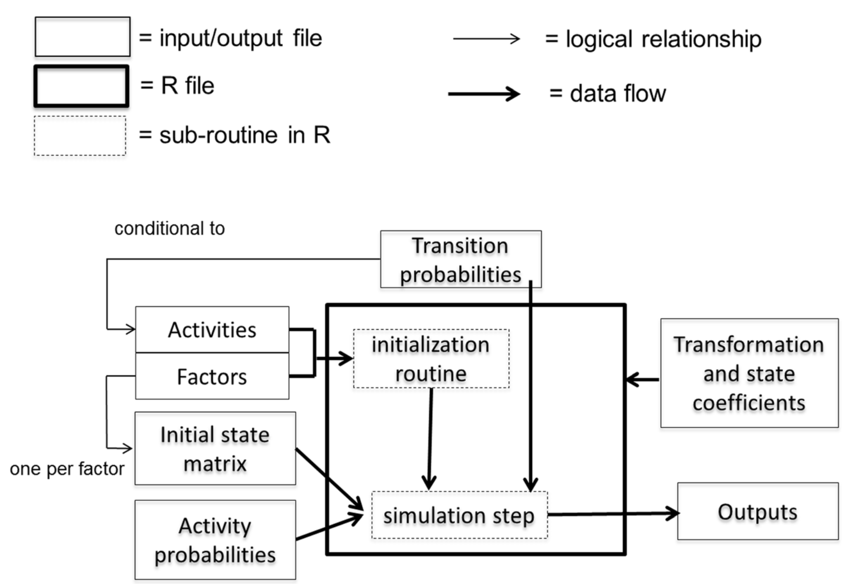

Fig. 1 The parameter environment of the EFDM simulation runs

Table 1 Central characteristics that can be extracted from the metadata of the simulations for the different countries

Identity[a]		NFI information[b]		Forest area[c]			Model parameterisation[d]			
Country	Group	Year	PPFs	Total, 1000 ha	FNAWS, %	FRAWS, %	Silvi	Factors	$Plots_N$	$Plots_A$
Austria	CW	2008	1, 2, 3	3716	5.7	8.9	U	7	7714	8094
Belgium*	CW	2001	1	480[§]	–	–	N/A	N/A	4483	4483
Czech	CE	2012	1, 2	2846	5.0	–	E	6	12911	9439
Denmark*	NE	2012	1, 2	583	3.9	–	E/U	16	3100	N/A
Estonia	NE	2005	1, 2, 3	2234	9.7	13.0	E	6	4154	N/A
Finland	NE	2011	1, 2, 3	21282	10.1	10.6	A	7	11987	10839
France	CW	2014	1, 3	16866	5.3	18.3	U	6	51343	10782
Germany	CW	2002	1, 2, 3	10299	0.8	3.7	E	6	15847	30023
Hungary	CE	2012	1, 2	2142	3.2	–	E	4	5184	5184
Ireland	CW	2012	1, 2, 3	637	0.6	15.7	E	6	1712	1712
Italy	SW	2005	1, 2	8525	6.2	–	A	5	5536	5536
Latvia	NE	2012	1, 2	3283	2.9	–	E	7	16157	16157
Lithuania	NE	2000	1, 2, 3	2024	1.2	11.7	E	6	10800	2400
Norway	NE	2014	1, 2	12287	2.0	–	A	7	12084	12084
Portugal	SW	2005	1, 2	2645[§]	40.7	–	U	3	4574	N/A
Romania	CE	2010	1, 2, 3	6900	2.0	12.7	E	4	22518	22518
Serbia	SE	2006	1	2252	10.2	–	E	4	4809	4809
Slovakia	CE	2005	1, 2	2213	2.0	3.1	E	4	741	1280
Slovenia	SE	2012	1, 2	1216	10.0	–	U	5	518	190
Spain	SW	1990	1, 2	1057[§]	5.3	–	A	6	3186	1087
Sweden	NE	2010	1, 2	23115	3.8	–	E	7	68399	68399
Switzerland	CW	1995	1, 2	1103	37.2	–	U	5	2988	2541
UK	CW	2013	1	2644[§]	–	–	E	6	14337	14337
All		2012	1, 2	130349	5.9	5.8	E	6	285082	231894

[a] Name of the country and country group corresponding to UNECE/FAO (2011): CE, Central-East; CW, Central-West; NE, North; SE, South-East; and SW, South-West Europe. Asterisks (*) indicate that countries used national models for the analyses, while all others used the EFDM. "All" column is either the mode, mean, or sum depending on the context

[b] Average measurement year of the inventory campaign and Production Possibility Frontier (PPF) points that could be computed under administrative forest use restriction categories available in the NFI data

[c] Total forest area analysed and percentage of Forests Not Available for Wood Supply (FNAWS) and Forests with Restrictions on Availability for Wood Supply (FRAWS) of the total area. Section (§) signs indicate that the analyses were focused on specific regions or areas dominated by certain species rather than entire countries. Hyphens (-) indicate that information on the respective administrative restriction categories was not available in the NFI data or was not processed

[d] Parameters affecting the future simulations: Silvi, silvicultural system; E, even-aged; U, uneven-aged; and A, any-aged; number of factors and sample plots for parameterising the transitions due to natural processes (N) and management activities (A) in the EFDM. Not applicable (N/A) in these columns refers either to simulation logic being based on different definitions (see Section 2) or that no management activities were assumed in the simulations

define what EFDM factor levels were relevant from the management perspective (e.g. the level of aggregation similar to other growth simulators typically applied in the area). The different PPF points were then produced by altering allowable activity probabilities (Fig. 1) for the FAWS, FNAWS, and FRAWS categories according to the definitions of PPFs. The transition probabilities were derived from the best available sources such as repeated measurements of permanent inventory plots; growth data from temporary inventory plots; growth simulators; or expert opinion, according to what was considered relevant and feasible for each country. The parameterisation of the factor levels, transition probabilities, activity probabilities, and output coefficients, in addition to possible deviances from the aforementioned documents used by some participants for their analyses, are presented in the description file associated with the dataset.

2.2.2 Other modelling approaches

The calibration of the EFDM proved difficult based on NFI data from the southern Belgium (Wallonia), Denmark, and UK because of reasons such as (1) high fragmentation and heterogeneity that were not captured by the NFI; (2) short time span covered by NFI data; and (3) rapid changes in the composition and management of forests in Wallonia (Alderweireld et al. 2015) and intensive afforestation and management of forests in Denmark.

The projections in Wallonia were simulated using an in-house Forest Simulation Software (FSS). It integrates tree-level, distance-independent growth, regeneration, and harvesting models that were fitted on data from the Regional Forest Inventory of Wallonia (RFIW) measured between 1994 and 2015. These models take into account the species composition, stand density, site characteristics, tree size, social status, and the type of forest ownership. Aerial photographic interpretation was used to update the status of each permanent forest sample plot monitored by the RFIW. The fitted models and the results of the photo-interpretation were applied on 95,310 virtual forest stands generated from the most recent RFIW data to provide outputs comparable with those based on the EFDM.

In Denmark, the modelling was based on the method described by Johannsen et al. (2017). Similarly to the EFDM, the model applies transition probabilities in a Markov model setup for the development of growing stock volume and carbon. The fellings are based on the deduced area development and activity data are based on yield models. This modelling approach yields outputs comparable with the EFDM based on the NFI results from Denmark.

The model for UK takes mensuration data from the NFI plots (measured 2010–2015) along with the Forestry Commission's Sub-compartment database (SCDB) and uses it to assign a yield class and predictive growth curve based on data collected since 1919 by the Forestry Commission in yield plots and thinning and spacing experiments. These growth curves are applied under an agreed set of management assumptions for each sub-component of woodland within the plots. Each stand of trees, in an NFI sample square or within the SCDB, is represented spatially, together with information on individual stand characteristics (e.g. species, planting year, spacing, and yield class) which is periodically updated. Biomass is calculated from a model that takes the output of these forecasts and makes use of independent allometric equations based on the approach in published scientific literature (McKay et al. 2003). This calculates the volume of the crown, roots, and stem and makes use of the relevant species-specific nominal specific gravity of the timber (Lavers and Moore 1983). Estimates of total carbon in the trees are then derived by multiplying the biomass estimates by a value for the carbon content of tree biomass. The forecast options selected and restricting output to above-ground carbon gave outputs comparable with the EFDM.

3 Access to the data and metadata description

The dataset can be downloaded using the following reference and doi (Vauhkonen et al. 2019). Data from: Harmonised projections of future forest resources in Europe. Dryad Digital Repository, https://doi.org/10.5061/dryad.4t880qh. The metadata of the entire dataset are available at https://metadata-afs.nancy.inra.fr/geonetwork/srv/eng/catalog.search#/metadata/8f93e0d6-b524-43bd-bdb8-621ad5ae6fa9

The dataset covers two files named dataset.csv and README.xlsx. The dataset.csv file is provided as a standardised, comma-separated (csv) text file. It contains the country-specific projections of the forest growing stock volume, above-ground carbon, and fellings in the area analysed. The README.xlsx file contains altogether 29 worksheets as described below. The "Information" sheet provides a brief description and a reading instruction for the dataset. "DATA_DICTIONARY" provides the acronyms, definitions, and units for all variables used in the dataset. "PARAMETER_ENVIRONMENT" provides details on how the future projection model (cf. Fig. 1) was parameterised by the NFI data and forestry practices of each country. "CLASSIFICATION_RULES" presents the definitions according to which FNAWS and FRAWS were distinguished from FAWS in countries that applied these categorizations in their analyses. "TOTAL_RESULTS" shows how the results can be combined and example graphs prepared for discovery and exploratory purposes using some limited Excel functionality. The remaining sheets present the results for each of the 23 countries and the "template" on which the information was requested. The metadata reports geographical data coverage, providers, accessibility, context, (material, methods, simulation protocols, and analytical perspectives), and technical details (description of all variables and fields in the dataset).

4 Technical validation

Central characteristics were extracted from the metadata of the simulations and used to describe the extent and reliability of the analyses of each country (Table 1). According to Table 1, the analyses covered altogether approximately 130 mill ha of forests in Europe, of which 5.9% and 5.8% were FNAWS and FRAWS, respectively. The definitions of FNAWS and FRAWS for those countries that excluded these categories from FAWS varied as presented in the description file associated with the dataset. The proportion of FAWS, FNAWS, and FRAWS of the total forest area as well as the key simulation parameters for the future projections varied considerably between the countries as shown in Table 1 (see also the next section).

As a further validation of the dataset, the following results were examined and verified to demonstrate that they credibly depict the different European countries:

- Analyses of the temporal development of the growing stock volume, above-ground carbon, and harvests, which can be illustrated and analysed for individual countries, country groups, or, as in Fig. 2, including all countries that computed at least two PPF points.
- Analyses of relationships and trends between the attributes mentioned above. Figure 3 presents growing stock and fellings derived from the different countries as the three PPF points that assumed different wood availabilities. In principle, the points connected by lines can be considered as estimated, business-as-usual production frontiers of individual countries or country groups.
- Analyses of how the administrative restrictions in the forest use affect the future development of forest resources. Figure 4 presents a comparison of different forest use restrictions of each analysed country to an unconstrained situation. A policy or decision maker planning a feasible level for forest use restrictions could benefit from knowing the dependencies and uncertainties between constrained forest area and the development of forest resources (Fig. 4).

The main benefit and difference of our data compared with other European wide projections such as the EFSOS-II data are that Figs. 2, 3, and 4 present harmonised outputs, even though forestry practices prevailing in individual countries are largely taken into account during the computations. The projections should consequently be more compatible, when assessed at a national level, although this statement is difficult to validate except qualitatively, as done by reasoning above.

5 Reuse potential and limits

While the previous section provides an example of the results that can be derived from the datasets, it is worth noting the limitations on providing similar results. The derived results should be presented pro rata with information presented above and in the metadata; i.e., the resulting figures should be interpreted with respect to administrative restrictions and parameterisation of the simulation models applied in each country, for example as follows:

Our PPFs are not optimised and should therefore not be interpreted as Pareto-optimal production frontiers achieved when the given resources and technology are optimally used, which is a common definition for a PPF. If optimisation was applied to enable a more efficient use of resources, it would shift the PPFs farther from the origin, which compares with a shift caused by technological improvements in typical analyses of Pareto-optimality. As described above, our PPF points are mainly to illustrate the combinations of future forest attributes that are possible, if different degrees of area (determined by the administrative restrictions) are available for wood supply and a business-as-usual management is projected to this area.

The various ecological, technical, and socio-economic constraints included as the forest use restrictions are assumed to account for these dimensions of sustainability. However, the applied business-as-usual management is not necessarily sustainable because the specific constraints on this aspect were not explicitly considered. Our harmonisation work indicated that definitions related to maximum sustained yield and, consequently, sustained harvests varied between countries. Although business-as-usual management thus provided a sensible baseline for comparisons, it is a relevant future topic to compare these projections with “Maximum possible”, “Maximum sustained”, or such harvest levels that are allowed by the LULUCF Regulation (EU, No 2018/841), for example. Furthermore, continuation studies integrating forestry dynamics with economic dynamics (supply and demand) models are obviously needed. Earlier studies have shown the possibility to couple the EFDM with econometric models (Jonsson et al. 2016) and parameterise the EFDM to produce carbon-related metrics under climate-induced uncertainties (Vauhkonen and Packalen 2018) or changes in future forest use (see also Vauhkonen and Packalen 2019).

The computations required to define the distinct PPF points should not be interpreted as if those were scenarios realising in the future. While the PPFs with the highest number available per country are based on the business-as-usual transition and activity probabilities derived from the NFI data and/or expert knowledge, especially PPF 1 is hypothetical and produced only for comparison for the situation where no administrative restrictions exist. Furthermore, all computations assumed an undisturbed development according to the business-as-usual transition and activity probabilities. For instance, natural disturbances or calamities, together with possible salvage logging, can increase fellings and affect the development of biomass and carbon compared with the projections presented.

We did not focus on the quality of the initial state information for the projections, but assumed that the measurement and estimation protocols of the NFIs applied in Europe (e.g. Vidal et al. 2016) provide reliable initial information for the computations. Nevertheless, the reader should note that for instance the base years of the inventory vary considerably between countries (Table 1). The NFI sampling grid density, the number of NFI plots, and number of completed NFI rotations vary between countries (e.g. Serbia and Slovenia). These factors or their combinations could have a great influence on the final predictions and the prediction uncertainties. However, these sources of variation are fundamentally related to the use of NFIs and thus present also in projections such as those used

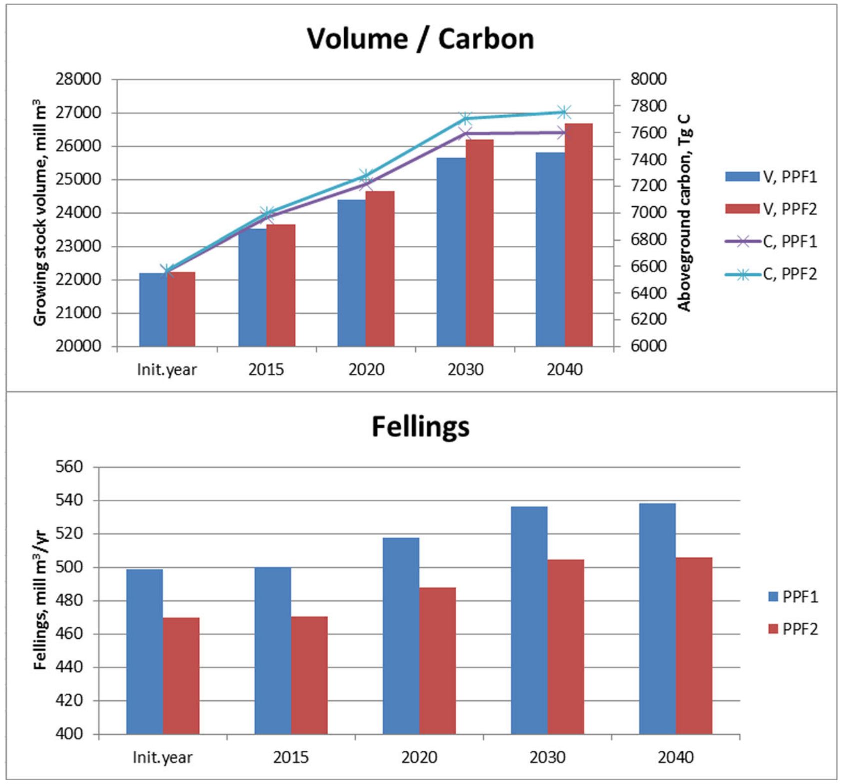

Fig. 2 Temporal development of the growing stock and above-ground carbon (above) and fellings (below) carried out in the entire simulation period. The figures include all countries that computed both the mentioned Production Possibility Frontier (PPF) points and France (PPFs 1 and 3) merged into the two categories. When interpreting the figure, the varying interval between time points given in the *x*-axis should be noted

in EFSOS-II. Also, while the definitions for FAWS and FNAWS are established (Alberdi et al. 2016; Fischer et al. 2016; Lind et al. 2016), FRAWS are not distinguished from these categories by NFIs of many countries and the related information may include many more sources of uncertainties (see below).

The projection models were parameterised individually by national experts in relation to available data and country-specific forestry practices and assumptions for the future. Nevertheless, the difficulty of parameterising, especially the EFDM, probably increases via increasing number of factors required for describing the current forest state and forest management practices. The difficulty is probably magnified, if a low number of plots for parameterising the transition probabilities of growth and activities are combined with a high number of activities and factors used to describe the state space and activities. Even if the EFDM includes internal functions to include prior information for relaxing on the need for vast data for the transition probabilities (e.g. Sirkiä 2012), the prior information is defined in terms of age-based forest dynamics. Both even-aged and uneven-aged simulations result to equal accuracy, if parameterised with sufficient data (Vauhkonen and Packalen 2017). With a small amount of data, the parameterisation of uneven-aged forestry dynamics can be deemed more uncertain than even-aged forestry dynamics. However, the future projections are inherently uncertain and their reliability depends on whether the assumptions on business-as-usual transitions and allocation of management activities still apply in the future (Vauhkonen and Packalen 2018).

Due to these limitations, our data should be considered as a pilot study or first example of deriving comparable information from European NFIs by harmonising definitions, assumptions, and modelling methodology. The dataset may readily be a useful source of data for analyses requiring comparable information: Due to the harmonised approach, the results can be easily compared with other projections either at the level of individual Member States, country groups such as those corresponding to UNECE/FAO (2011), or at the European level. Comparing the results with those computed for the same scale using less harmonised approaches such as national projection models may provide useful insights on the effects that harmonising may have on both national/international policy and decision-making.

The role and definitions related to the FRAWS category clearly vary more between countries than those related to the other two categories, which can be due to low representativeness of these areas in NFI data and including restrictions occurring because of multiple reasons in just one category. Yet, in countries where the FRAWS are distinguished, the treatment of these areas in future simulations may have strong influences on the projections of the wood supply (Figs. 3 and 4). While distinguishing features were identified to differentiate between FAWS and FNAWS that proved useful for defining PPFs, further work is required to assess whether the

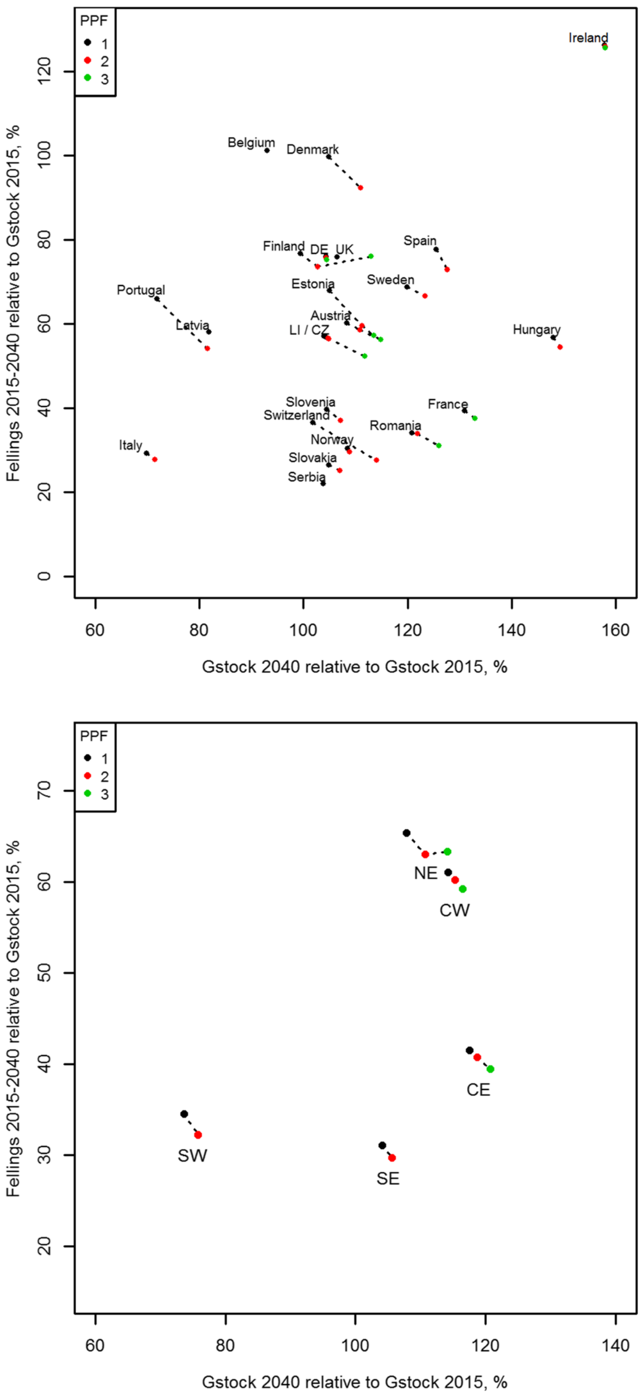

Fig. 3 The development of growing stock (Gstock) between 2015 and 2040 vs. fellings 2015–2040 for individual countries (above) and country groups (below). Scenarios computed by a country are connected by dashed lines. Countries Germany (DE), Lithuania (LI), and Czech Republic (CZ) are presented by abbreviations because of overlapping values in the diagram. Note that the values of Production Possibility Frontier (PPF) points 1 and 2 for LI and CZ cannot be distinguished as being close to each other, but PPF point 3 was computed by LI. Country groups are abbreviated corresponding to UNECE/FAO (2011): CE, Central-East; CW, Central-West; NE, North; SE, South-East; and SW, South-West Europe

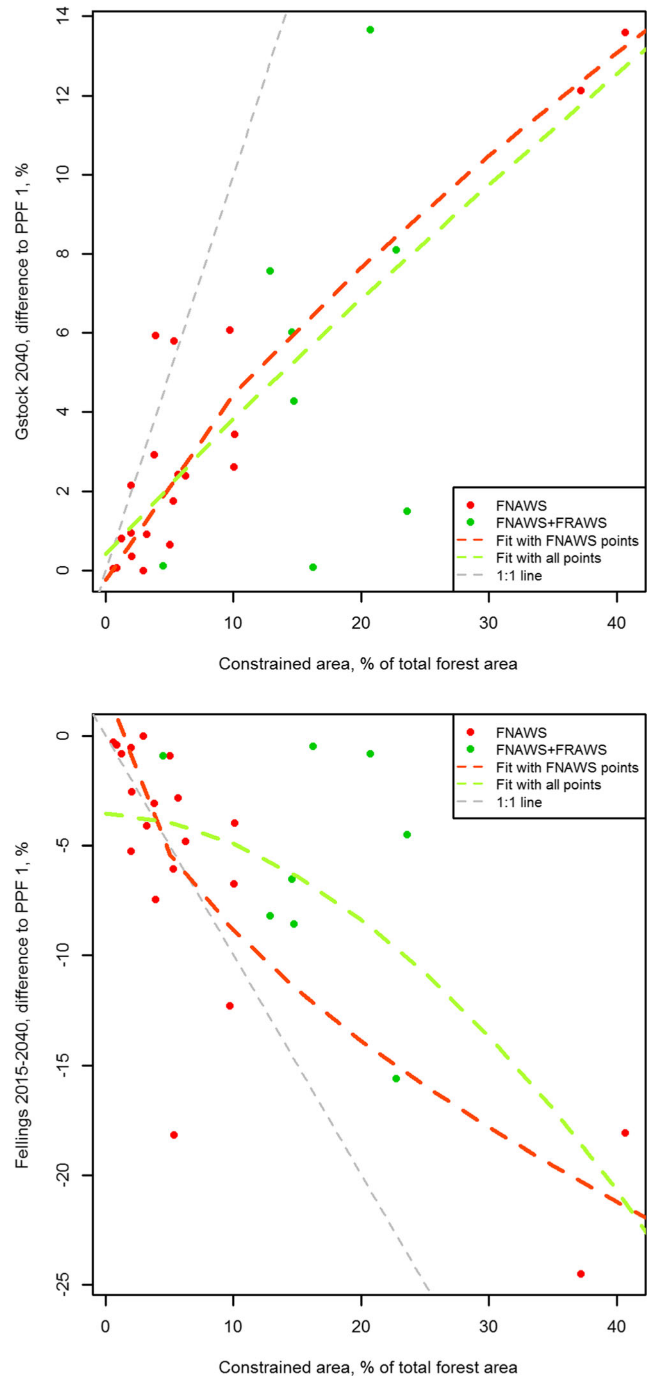

Fig. 4 The total growing stock in 2040 (Gstock; above) and fellings 2015–2040 (below) as a function of area constrained from wood supply, compared with a hypothetical situation where no constraints existed (Production Possibility Frontier, PPF, point 1). The figure was composed by computing the difference between PPFs 1 and 2 (shown as FNAWS points) or PPFs 1 and 3 (FNAWS+FRAWS points) and fitting second-degree curves to the data points obtained from all countries that computed the respective scenarios. FNAWS, Forests Not Available for Wood Supply; FRAWS, Forests with Restrictions on Availability for Wood Supply

FRAWS category can be logically defined and whether this definition results to a large enough sample in the NFIs to derive reliable information for the subsequent projections. Further studies should also consider a potential risk of over-harmonising due to the reality that constraints for wood availability greatly differ between countries in Europe and harmonising all restrictions would make sense only if the forestry policy across Europe was also harmonised.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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